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Chapter 9. Watershed Restoration—Adaptive Decision Making in the Face of Uncertainty

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Abstract.–Decisions about watershed restoration projects often are complicated by competing interests and goals, gaps in scientific knowledge, and constraints on time and resources. Under these circumstances, there is no best approach to decision making and problem solving. Appropriate decision processes need not always be analytically complex, but instead depend on the characteristics of the external social context, the decision makers, and the decision problem itself. Because social concerns so often prevail in restoration decisions, we begin with a discussion of issues characterizing the social context. Next, in three increasingly broad contexts for watershed restoration, we discuss the application of several methods for facilitating decisions and solving problems involving uncertainty: Bayesian decision analysis, active adaptive management, passive adaptive management, and evolutionary problem solving.

Introducing the Decision Toolbox

Uncertainty is a fact of life in watershed restoration. The preceding chapters of this book present a daunting picture of variation and gaps in knowledge about river ecosystems. How can managers hope to select effective restoration actions or make decisions about an ongoing project with so many management alternatives and such imperfect information? Fortunately, human beings have a long and rich history of making decisions and solving problems concerning complex systems with long response times and for which there is imperfect information. As a result, individuals and societies are endowed with a toolbox of decision-making strategies, precedents, and resources that can help to structure and legitimize the decision task, making it more understandable and manageable. This chapter explores how strategies for decision making and problem solving might be used to address watershed restoration planning and actions.

What can people planning a restoration project learn from the way individuals make decisions in ordinary life? Studies in cognitive psychology show that people are generally competent, adaptive decision makers in most real-life situations, intelligently applying strategies for assessing alternatives, even when faced with many options and considerable uncertainty (Payne et al. 1993). Appropriate decision strategies depend on three situational components:

- the decision problem itself–for example, information gaps, need for accurate information, effort required to get that information, possibility of reassessing the decision in the future;
- the internal social context–for example, the decision makers' expertise, analytical resources, accountability, social relationships, and communication networks; and
- the external social context–for example, societal values and goals, accountability and group membership of stakeholders, geography, and timeframe

Often, even in routine situations, the need for accuracy and the effort of acquiring information

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become key elements in an adaptive approach to decision making. Accuracy and effort trade off against one another because collecting or improving information is usually costly or time-consuming. People with limited time often consider only a small set of crucial criteria, eliminating alternatives that fail to achieve satisfactory results on each, rather than gathering all the information about all the alternatives. An employer faced with a thick pile of job applications might decide to eliminate all those with less than 5 years' experience, for example. Another strategy, commonly used when information is incomplete, is to begin with a provisional choice and reassess the choice as the situation unfolds. A baseball manager does this when he chooses a starting pitcher with the expectation that a reliever may be needed later, depending on the starter's performance. Our intuitive decision strategies, streamlined of necessity by the accuracy–effort tradeoff, may not produce the optimal decision in every case, but they serve us well. In many real-world situations, especially those with incomplete information, they actually outperform complex, theoretically ideal decision processes (Gigerenzer et al. 1999).

Various human collectives have also produced workable formats for formidable decision-making tasks. For example, jurisprudence and many modern medical protocols include standardized, adaptive decision strategies developed and practiced within those groups. These well-defined procedures do not guarantee the correct decision in every instance but their overall performance is transparent, appropriately open to new information, and generally accepted by the public despite some fallibility. Another example, appropriate for urgent or emergency situations, is triage, a strategy that is socially sanctioned in certain circumstances to concentrate scarce resources on cases that require, and will likely benefit from, immediate help. While these institutionally mandated decision strategies do not share all the flexibility of adaptive individual decision processes, they do structure their respective problems in a way that helps balances the expertise and analytical abilities of the individuals involved, acknowledges the social context, and achieves an acceptable compromise between accuracy and effort.

Decisions concerning river restoration projects, of course, cannot rely on simple intuitive strategies or socially mandated decision-making protocols developed for other purposes. However, planners of restoration projects can benefit from understanding the factors that contribute to successful decision processes and problem solving in general. As we have seen, an adaptive decision strategy is one that is appropriate to the analytic resources of the decision maker(s), the external social context, and the particular problem. In the restoration context, this implies that project planners must understand the disparate goals of stakeholders, which proceed from the external social context. Planners should be aware of uncertainties about the river ecosystem and the tradeoff between their importance and the time and effort required to resolve them, given the available analytic resources and the ability to pass information on to future managers. If possible, the restoration plan should provide for a response to new information as the restoration unfolds. The unfolding will often occur over a long time scale, a requirement that particularly demands ingenuity in dealing with the social and institutional context.

There is no best method for problem solving and decision making under these circumstances. However, mindful use of elements from our species' "adaptive decision strategy toolbox" (Payne et al. 1993; Gigerenzer et al. 1999) will improve confidence in problem solving and decision processes, helping to neutralize surprises and avoid wasting resources on options that have little chance of public acceptance. Thus, an early step in planning a restoration project should be to characterize the three situational components to discover which problem-solving and decision "tools" will prove useful in dealing with uncertainty as the project unfolds (Table 1).

Once the situational components are characterized, the next task is to identify a suitable strategy for decision making or problem solving. We examine this notion of suitability by describing four strategies for adaptive decision making and restoration situations in which each might be

TABLE 1.–Questions useful in characterizing a watershed restoration problem with respect to adaptive decision and problem-solving strategies.

Nature of the problem
- Is there a tradeoff between accuracy and effort or time?
- Is the system easily divided spatially or temporally?
- How can we recognize a satisfactory decision or measure progress toward a solution?
- How long will it take the system to respond to proposed management actions?

Internal social context: the decision makers
- Will the problem solving or decision making be carried out by an individual or by a group?
- What kind of scientific analysis will the decision makers be able to understand and convey to others?
- Can the social relationships among the decision makers be adjusted to match the requirements of a decision strategy?
- What consequences will the decision makers experience if they undertake an experiment or innovation?

External social context: values, geography, and time
- If there are multiple goals, do their objectives suggest related metrics, or are they incommensurable?
- Is the social context easily divided geographically or along other dimensions?
- Can we expect social conditions and goals to change over time?
- Are there legal or political time constraints?
- Where does science fit in?

appropriate. The four strategies are static decision making, passive adaptive management, active (experimental) adaptive management, and "evolutionary" problem solving.

Static decision making. Flexibility and ongoing review are important characteristics of adaptive decision making, but they are not the only criteria. A "static" decision strategy–taking the information available now and determining the best restoration plan in a single decision, can qualify as adaptive decision making if it is structured to improve clarity (Payne et al. 1993) and to take explicit account of uncertainty (Peterman and Anderson 1999). A static decision strategy, moreover, may be quite appropriate if learning from the situation is deemed unimportant in the social context or requires too much effort, or if the people involved with the project over time will not have adequate analytic tools to make use of accumulating information.

The next two strategies are forms of *adaptive management* (Walters 1986). Adaptive management is the practice of selecting management actions that will help answer questions about the system being managed while coping with unexpected outcomes and uncertainties that cannot be quickly resolved. In adaptive management, learning explicitly gains a place alongside the more traditional economic, biological, and social goals.

Passive adaptive management plans use the information available to choose good management or restoration options at the start, but they also specify future decision points where feedback and new information are analyzed so that the choice of subsequent restoration actions is based on the total information available at each decision point.

Active (or experimental) adaptive management formally experiments with management options in different places or different times to test hypotheses about the system and management options as quickly as possible. An actively adaptive restoration plan might define a 5- or 10-year "learning period" in which various management or restoration options would be implemented in different places, preferably in a well thought out experimental design. After the learning period is completed, the management options that appear to be best at that time would be implemented more widely. The learning period is not a delaying call for more research. The experimental program begins during the learning period on the same spatial and temporal scale as the main restoration activities.

Both passive and active adaptive management rely on ongoing monitoring and multiple decision points. They differ in that passive adaptive management chooses the best apparent management option at each decision point, while active adaptive management tests hypotheses by exploring a range of options in the early phases. They also function best in well-bounded systems with goals and objectives that are clear and stable throughout the period of experimentation and decision points.

With their emphasis on learning, both forms of adaptive management transform management activities into science. "Science," far from an abstraction, is a complex process of changing beliefs that depends critically on the social arrangements of scientists working within a field (Hull 1988, 2001). Therefore, any attempt to apply adaptive management calls for a good understanding and appropriate arrangement of the internal social context.

In particular, three critical elements–*curiosity*, *credit*, and *checking*–seem to make science efficient by helping the individual interests of scientists coincide with the more abstract, shared goal of learning (Hull 1988). Curiosity is required because of the time and effort needed to do scientific research. Scientists must care deeply about the questions they are investigating. Credit is the currency that enables individual scientists to "own" ideas, hypotheses, and results; it is enhanced for those who can establish priority. The prestige that scientists receive when their results are cited *and used* by other scientists is central to the notion of credit. The credit system of science contributes to prompt publication, openness, and sharing of information.

Finally, checking occurs when scientists depend on each other for reliable results to adapt and use for their own purposes. The fact that other scientists will use one's work, and that use will eventually expose any errors, motivates scientists to strive toward accuracy and to submit their work to review before publication. This interplay of cooperation and competition increases efficiency by reducing the need for scientists to check one another's work before using it.

"Evolutionary" problem solving. Evolution by natural selection, we know, can produce progressive improvement and adaptation of organisms, in the absence of an omniscient planner or a single well-defined goal. Organisms are not the only things that can evolve. Any system that contains the elements essential for evolution–many varying units exhibiting differential success, and the tendency for the most successful to be copied in the future–may also evolve over time (Dennett 1995). In particular, cultural change is often evolutionary as ideas and technologies vary and compete, with the most successful ones being imitated by, or taught to, others. Some theorists of cultural evolution underscore this parallel with biological evolution by referring to units of cultural practice as "memes," which, like genes, change in frequency over time (Blackmore 1999). Indeed, Hull (1988, 2001) suggests that accumulation of knowledge in science may occur through processes that are partially evolutionary in nature.

Brunner and Clark (1997) have proposed that an evolutionary process should be harnessed for a somewhat different purpose: improvement in the practice of conservation biology. Difficult problems in applied ecology, such as ecosystem management, may be effectively tackled if interactions among the practitioners are *explicitly structured* so as to facilitate evolutionary improvement. Brunner and Clark suggest that evolutionary improvement in practice is enhanced when the internal social environment encourages the following:

innovation–a number of small, independent projects ("prototypes") intended to address a practical problem,

diffusion–agreement on important variables to monitor and efficient, regular communication among the people involved with the projects, and

adaptation–selecting and adapting the most promising examples to new circumstances.

Explicit structuring to encourage these three processes differentiates evolutionary problem solving from mere "trial and error."

Brunner and Clark (1997) observe that evolutionary problem solving does not require a firmly defined or internally consistent set of goals and objectives. The United States Constitution, for example, assumes a set of vague, abstract goals for the relationship between citizens and their government (justice, domestic tranquility, common defense, general welfare, and so on). The manifestation of that relationship in practice has evolved and adapted over time (e.g., via multiple court decisions). The important point is that Americans see enough progress in solving particular problems to renew their commitment to the general principles despite apparent incompatibilities among the goals and the tendency for the practical implications of those goals to evolve over time. The progress must be apparent to the public despite the inevitable failure of some prototypes; evolutionary processes are, by nature, inefficient.

Evolutionary problem solving is especially appropriate when multiple goals are incommensurable (i.e., lacking a common measure or basis of comparison). In this type of decision process, the choice among cases or prototypes to adapt for future use does not depend on devising and maximizing a single quantity to represent all the goals. Instead, as information is gathered and disseminated, quantitative and qualitative results may be supplemented by a narrative sharing of experiences. The evolutionary approach thus takes advantage of people's ability to make decisions and solve problems by gathering cases and stories from experience, which is probably another element from our species' "adaptive decision strategy toolbox" (Riesback and Schank 1989; Anderson 2001).

Together, Tables 1 and 2 provide guidance for assessing a strategy for decision making or problem solving: When the answers to questions in Table 1 correspond well with the characteristics of an adaptive decision-making approach, such as those described previously and summarized in Table 2, that strategy may be suitable for the situation at hand.

Our goal is to investigate how these strategies for decision making and problem solving might be used in addressing problems of watershed restoration in the Pacific Northwest. First, we discuss the component of adaptive decision making that is most often ignored–the external social context. Next, we present three discussions of adaptive decision strategies. The first, the Gambler's Creek example, demonstrates how a simple decision analysis can help managers to structure their understanding of a restoration problem in the face of uncertainty, bringing adaptive elements into a static restoration decision. Second, the Cedar River example shows how managers might develop a passive–adaptive approach to a large restoration proposal based on judicious use of incomplete information and an awareness of the accuracy–effort tradeoff. Finally, we evaluate opportunities for active and passive adaptive management and for evolutionary problem solving in the *Basinwide Salmon Recovery Strategy* (Federal Caucus 2000), which will unfold in the context of the multiple and often intransigent social values and goals concerning Columbia River Basin Pacific salmon *Oncorhynchus* spp.

Characterizing the External Social Context

To illustrate the considerations that help in structuring a decision process, we examine the external social context of river restoration in the Pacific Northwest, addressing the issues listed in the last section of Table 1. We also discuss how those characteristics are intensified with respect to the specific problems associated with recovering endangered salmon populations in the Columbia River Basin.

Does the Uncertainty Result from Multiple, Incommensurable Goals?

Restoring rivers and watersheds might seem to be predominantly a technical or scientific challenge. However, ecological restoration is simply a *tactic* or *tool* to achieve particular societal policy goals. The most important initial question when considering the goals of a restoration project is, What does society want from the ecosystem in question?

TABLE 2.–Characteristics of four adaptive decision- and problem-solving processes.

	Static decision making	Passive adaptive management	Active (experimental) adaptive management	Evolutionary problem solving
Characteristics related to the nature of the ecological problem				
Units under consideration	One project	One or more projects	One experiment (usually involving several projects as replicates)	Many small, independent prototypes
Ongoing monitoring	Not required	Essential	Essential	Essential; coordinated among projects
Decision points	Single–assumptions about all future conditions and actions are made at the time of analysis.	Multiple	Multiple	Multiple
Choice at decision points	Best apparent management option is chosen at start of program.	Best apparent management option is chosen at each decision point.	A range of management options is explored in early decision points. Inferences are made and best apparent management option chosen and applied at later decision point.	Managers copy and adapt features of the most successful prototypes as they share experiences. Particularly promising cases are singled out for intensive study.
Characteristics related to the internal social context				
Analytic requirements	High, if all decision analysis steps are completed.	Moderate to high; reliability of learning depends on quality of monitoring and time-series analysis.	High, including experimental design and statistical analysis at end of experiment when inferences are made.	Low to moderate; progress in improving practice depends largely upon design of communication processes.
Social organization required of the decision makers	Decision process is not dependent on social factors, but stakeholders should help develop the decision tree.	Continuity of oversight; time-frame may exceed manager's professional "lifespan."	Managers must become scientists, so social organization must nurture *curiosity*, *credit*, and *checking*. Timeframe may exceed manager's professional "lifespan."	Social organization must facilitate *innovation*, *diffusion*, and *adaptation*.
Characteristics related to the external social context				
Goals and objectives	Goals must be clearly defined at the outset, with quantifiable objectives. Outcomes are evaluated with a single metric.	Goals and objectives should be clearly defined.	Goals will include a balance between management goals and learning. Hypotheses to be tested must relate to those goals.	Multiple, incommensurable goals are the norm.
Uncertainty and learning	Uncertainty is explicitly included in initial choice, but will not be resolved.	Learning is a goal, but information at later decision points may be unreliable, owing to possible confounding factors.	Learning is a goal, and a good experimental design should produce reliable new information for later decision points.	The chief benefit is improved practice over time, but learning about causation will usually occur as well.

Unfortunately, political institutions, including the law, rarely produce explicit policy goals. Policy goals can be difficult to specify for several reasons: the goals themselves are often nebulous and they have a frustrating characteristic of evolving over time. Moreover, even if stakeholders have clear ideas of their own goals, conflict among stakeholders may prohibit selecting a single coherent, shared goal. Thus, the negotiations of the political process often *intentionally* produce a vague, bland, general goal with which few disagree.

This problem looms large with respect to the goals of watershed restoration. A deceptively simple goal, such as restoring a system to a pristine wilderness state, is commonly unattainable. More typically, society has multiple, conflicting preferences for an ecosystem (e.g., hydroelectric power, mineral extraction, fishing, irrigation, transportation, outdoor recreation, species protection, economic development). In addition, ecological restoration goals often become entangled with the realms of ethics and the philosophical ideas of man's place in nature. The response to the Endangered Species Act (ESA) listing of salmon in the Columbia River Basin brings these issues into sharp focus.

The debate over the listing of salmon stocks as endangered species is characterized by strongly diverging ethical points of view. Some people feel that it is simply a matter of choosing among options, much as we do with choices over energy, transportation, or international trade policies. Resolution is achieved by following the classic political process of coming to agreement by compromise and tradeoff (Lackey 1999). Others view the decline of salmon in the stark terms of right and wrong. There may be references to the importance of protecting species because of their commodity value or their use as surrogates for environmental quality, but the issue is inherently whether humans have (or should have) a right to drive a species to extinction. Still others hold strong moral and ethical views on salmon decline, but view the issues through the prism of competing rights, such as the rights of the public versus the rights of individuals. An example is the ongoing debate over the legal interpretation of when a public policy action constitutes a "taking" of private property and financial compensation to the owner is required. One perspective suggests that regulations to achieve salmon preservation should not require anyone to relinquish his private property without compensation. The counter argument is that those individuals or groups that exacerbate the salmon decline or impede recovery ought to bear the cost of recovery.

If a participant in the policy debate perceives the salmon decline, for example, as fundamentally a moral or ethical issue, it is not realistic to expect a political compromise. Such strongly held policy positions mean that the ultimate resolution will be perceived unconditionally as win–lose (Lackey 1999). Thus, the emergence of truculent adversaries in the debate over salmon recovery is no surprise. The tendency to denigrate the motives of other combatants is unfortunate, but it is symptomatic of the central place that moral integrity rightly occupies in most people's minds.

The political process in democratic societies sometimes produces strong disincentives to specifying goals, exacerbating the uncertainties of the social context. Democracies have historically selected among competing ethical and philosophical stances in a way that has proved acceptable to a majority of citizens. At the same time, however, democratic political process tends to discourage elected officials and public servants from asserting leadership or taking a firm position that may alienate large numbers of people. With respect to watershed restoration, this often amounts to discouraging responsible officials from clearly articulating a set of goals and objectives for a project.

Differing views of man's place in nature also produce uncertainties. At one end of the spectrum are a cluster of beliefs that might best be called *biocentric*. People with biocentric views consider maintenance of ecosystem health or integrity as a primary goal of human activity. At the opposite end of the continuum is a cluster of *anthropocentric* political preferences. Those people holding anthropocentric views tend to believe that "benefits" (tangible or intangible, short- and long-term) accrue only to human beings. Although they often acknowledge that ecosystems can be adversely affected, they generally envision that sustainable benefits are possible from ecosystems with careful management.

Not surprisingly, people differ in their commitment to fight for the preservation of every ESA-listed species. Resources flow much more readily in support of charismatic or highly symbolic animals (e.g., eagles and salmon) than to endangered plants or insects. Supporters of the ESA suggest that this and other problems with its implementation could be ameliorated by changing the act. For example, the act could be broadened to emphasize protection of ecosystems and habitats, not individual species, and to provide for earlier intervention rather than focusing on species or subspecies already in perilous condition.

Because of uncertainties produced by these conflicts, some skeptics question how democratic institutions can choose among options. In fact, this situation, in which broad democratic commitment to general principles proves difficult to implement on the ground, is precisely where evolutionary problem solving should be effective. For example, the costs of complying with the ESA sometimes fall heavily on private landowners who lose investments or face restriction on use of their property. This problem is partly addressed by the development of Habitat Conservation Plans (HCPs), which license private developers to take certain numbers of a listed species as long as they commit to a tradeoff program of conserving and restoring habitats for that species in other locations (Noss et al. 1997). The HCPs are becoming increasingly common, allowing observers to begin to assess their quality and effectiveness (Harding et al. 2001). It might be possible to encourage the three principles of evolutionary problem solving–innovation, diffusion, and adaptation–with the aim of improving HCPs in practice: HCPs are multiple, independent *innovations* with a common general purpose–to devise compromises that mitigate the difficulties of complying with the ESA. As the HCPs develop over the coming decades, *diffusion* of information about their successes and difficulties could be facilitated by such means as reviews, meetings, and thoughtfully structured databases. Finally, *adaptation* from successful cases should be easily encouraged, given people's propensity to adapt solutions to problems from previous cases they have experienced (Riesback and Schank 1989).

Is the Social Context Easily Divided Geographically or along Other Dimensions?

A practical technical requirement with any proposed restoration effort is to *bound* the system of concern. Because no useable quantitative definition of an "ecosystem" has been developed that works within public decision making, other approaches have been used to define the system of concern. Historically, this was accomplished by focusing on one or more species of concern over a defined geographic area: for example, migratory waterfowl and their flyways. The geographic limits of the flyway become the operational boundaries for the management analysis. Similarly, for managing game fish populations in a certain lake, the lake and its watershed then become the units of concern. In these cases the policy problem defines the boundary. Another option is to bound the system by what is relevant to a community or interest group. For example, a problem might be bounded with the intention of providing diverse options for hunters. No matter how boundaries are defined in ecological restoration, they end up largely being geographically based–a *place* of concern.

Ecologists who are oriented toward ecosystem processes feel profoundly uncomfortable with the idea of setting "anthropogenic" boundaries within the system under management. However, Table 2 shows that much of the power of adaptive decision processes derives precisely from dividing the system up in space or time or both. Once the utility of spatial and temporal boundaries is accepted, the most difficult problem is to determine how strongly the boundaries should reflect political divisions versus biological functions. For example, Smith (1994) explains how the relative weighting of political and biological divisions might affect decision and problem solving processes in the Columbia River Basin.

It is also important to consider how changes in types and sizes of boundaries (e.g., number of hectares and people) may alter problem definitions and the possibility of uncertain outcomes from policy decisions. A change in the size of the managed units may change the nature of the problem drastically, quite out of proportion to the numerical change in scale. For example, restoration actions recommended to help listed salmon stocks on the Snake River might differ from actions to be applied to the Snake River when it is considered as part of the larger Columbia River drainage, requiring distribution of resources among a very different set of habitat units and stocks. In addition, a change in physical scale can greatly increase the complexity of stakeholder negotiations.

If program planners do not understand the power to be gained from judicious boundary-setting for regions of concern, they may be tempted to gloss over decisions on boundaries. In a pluralistic society with varied and strongly held positions, the resulting uncertainty may intensify conflict when perceptive individuals and groups see how their position depends on the choice of problem boundaries. The resulting debates may appear to concern technical issues, but the real issue is a clash of values and priorities.

Reality of Restoration: Will Social Conditions and Goals Change over Time?

A brief historical perspective answers this question in the affirmative because species extinctions are not new in the Pacific Northwest. People have been moving to the region for the past 15,000 years and causing "problems" from the start. As recently as 10,000 years ago, the region supported mastodons, mammoths, giant sloths, giant armadillos, giant beavers, American camels, American horses, the American tiger, and the giant wolf–all are now extinct, probably owing to a combination of hunting, climate change, and possibly introduced diseases. It is the rate and scale of extinctions that are the issues today. Only catastrophic Pacific Northwest events such as major volcanic eruptions, massive earthquakes, and extreme climatic events are comparable.

The human population of the Pacific Northwest is growing and urbanizing rapidly. Given that this trend will probably continue, it may not be possible to restore salmon in many watersheds of this area. Dramatic changes in land use over the last few hundred years have altered aquatic environments in ways that no longer favor salmon (Chapters 5 and 6, both this volume). The Columbia River drainage, for example, is now dominated by hundreds of major dams that create series of mainstem and tributary lakes. As dramatic as the changes are, some fishes are thriving. Walleye *Stizostedion vitreum*, shad *Alosa sapidissima*, smallmouth bass *Micropterus dolomieu*, and brook trout *Salvelinus fontinalis* are exotic species that are well adapted to the new environment. Skeptics of restoration doubt we can recreate past salmon habitats. A simple, cheap option would be to manage for those fishes best suited to current habitat.

With respect to salmon management, the key concepts of stocks, species, and evolutionarily significant units (ESUs) are currently in flux and will probably remain labile into the foreseeable future, generating continued uncertainty about restoration goals and objectives. Where stocks are the unit of interest, it makes sense to rank them in order to improve the efficiency of efforts to protect and restore populations (Allendorf et al. 1997). This triage-like approach could concentrate restoration efforts in locations such as some coastal rivers, where reasonably healthy wild stocks still exist and the chance of success is greater. At the other extreme, a focus on species might suggest that no *species* of salmon is in danger of extinction, a conclusion that would be interpreted by some as diminishing the urgency of many restoration goals, and by others as admitting defeat in the face of difficult, expensive, and divisive policy choices. Finally, in the context of the ESA, settling on a definition of ESUs for salmon will be a long process involving the complex intersection of science and the court system. An example is the September 2001 decision in the U.S. District Court (District of Oregon Case No. 99–6265–HO, "Alsea Valley Alliance v. Evans"). Judge Michael Hogan ruled that the National Marine Fisheries Service (NMFS) could not list wild central Oregon coho salmon *Oncorhynchus kisutch* under the ESA because they had included hatchery fish in the designation of the relevant ESU, and the numbers of hatchery fish were sufficient to preclude listing. This decision has initiated a round of scientific review and public consultation by NMFS concerning the place of hatchery fish in ESUs and in restoration efforts.

The above perspectives suggest that goals concerning all Pacific Northwest watersheds are likely to change over time even if they are well defined and coherent at present. The implication for decision processes is profound. The optimal recommendation of a static decision process may prove to be unacceptable a few decades hence. Long-term passive and active adaptive management projects may find themselves "orphaned" if their objectives and hypotheses to be tested become irrelevant. Under these circumstances, as in jurisprudence and medicine, the decision-making procedures followed, and their documentation, become more important than particular results. Evolutionary problem-solving processes should be more robust to changing goals, as long as information is shared efficiently and promising prototypes are reevaluated often enough that innovations can track changing objectives and corresponding problems.

Are There Legal or Political Time Constraints?

Laws such as the ESA are usually considered as tools to help implement public policy, but this bland statement fails to convey the dramatic effect its time constraints can have on the accuracy–effort tradeoff in decision processes. For example, in 1995, NMFS issued a Biological Opinion on the Federal Columbia River Power System in response to the listing of several salmon stocks. A collaborative decision process, PATH (Plan for Analyzing and Testing Hypotheses), was formed to examine models of salmon dynamics in response to the NMFS Biological Opinion and court recommendations (Chapter 10, this volume). The PATH involved many stakeholders and was structured to address uncertainty and emphasize accuracy, calling for careful, multi-level review at every stage. This rigorous but unwieldy structure made it difficult for PATH to meet the timelines imposed by the legislation, and was partially responsible for the Federal Caucus' eventual preference for an alternative, more efficient analytic process, Cumulative Risk Initiative (CRI) (Marmorek and Peters 2001).

The ESA can also be used by particular groups to accelerate consideration of certain problems or to frame the decision or policy question in their terms. Those who believe the ESA should be invoked to arrest salmon decline usually insist that the act forces society to make necessary though painful tradeoffs, which are part of a last-ditch effort to save listed species. For the decision maker, then, the ESA sharpens the time dimension, so the accuracy–effort tradeoff becomes an accuracy–time tradeoff. This is especially true when no amount of money or manpower can make results come in faster, as is often the case with ecological systems.

Where Does Science Fit In?

The challenge for managers of ecological restoration is to determine the *goal* or *goal set* and then to design a strategy for implementing a *mix* of decisions to move in that direction. Though these processes are essentially political, they inevitably take place in a context of technical understanding or assumptions concerning the ecological system's capacity to achieve that goal. The major challenge to scientists is to provide information that improves our ability to predict outcomes of policy decisions. Though policy goals may be abstract and general, their associated objectives should be closely tied to scientific considerations. Objectives should be clearly stated, as specific as possible, quantifiable by some means (if not empirically, then at least subjectively), characterized by a performance measure so that restoration progress can be evaluated, and dynamic, reflecting societal preferences and ecological conditions or constraints as they evolve. These properties directly affect their use in ecological restoration.

Who should set objectives: agency personnel, the general public, or a combination of the two? Historically, those responsible for ecological restoration have consulted professionals in institutional (usually governmental) positions to set objectives. After all, they are the experts and many assert that they should know what is best for the resource. Critics term this an "elitist" planning process, but it does have the advantage of allowing the most qualified, knowledgeable people to determine objectives and make decisions to achieve those objectives.

Most professionals now advocate use of systematic public input (often legally required) in setting goals and objectives for a restoration project. An informed and concerned public is essential for decision making about ecological restoration in the current political climate. There are several benefits to involving the public in the planning process. A more democratic planning process should have a higher chance of success because it provides representation for those affected. Public discussions may shed light on the public response to potential restoration actions, and interactions between technocrats and the public may bring greater appreciation for both sides' viewpoints and problems. As part of this interaction, restoration technocrats should provide the public with understandable and credible assessments of the ecological consequences of various restoration options.

Public input must be managed wisely if it is to be beneficial. In practice, the "public" is usually defined as the stakeholders who have a vested interest in the project's outcome. Thus well-organized and well-financed stakeholders may have a disproportionate influence on the process. In addition, many restoration efforts fail because planners and managers do not consider the needs of certain key segments of the public or do not explain clearly that some goals and objectives are ecologically unrealistic.

Structuring a Static Decision with Decision Analysis

The social context impinges heavily on many watershed restoration problems, but in some cases the human dimension is relatively uncomplicated. In those cases, if some aspects of the ecosystem's response are uncertain, a static decision process may be helpful in choosing how to implement the project, as long as the boundaries, goals, and objectives are clearly defined. The technique presented here is Bayesian decision analysis (Raiffa 1968; Maguire 1988; Maguire and Boiney 1994; Peterman and Anderson 1999). With a single decision point at the beginning of the project, this type of static decision process confers several benefits:

- It structures the problem clearly.
- It provides a ranking of the restoration options even though the uncertainties may not be resolved in the foreseeable future.
- It helps the project planner to document and justify his decision process to others.
- It provides research priorities by showing whether resolving particular uncertainties would affect the preferred option.

In this example, traditional cost/benefit calculations for a restoration project, initially assuming no uncertainties, are expanded into a Bayesian decision analysis, taking into account untested assumptions and other uncertainties. When uncertainties are considered explicitly in this way, recommended actions can differ widely from the ones preferred under a deterministic approach (i.e., assuming no uncertainty).

Gambler's Creek: A Decision Assuming No Uncertainty

Scarfe (1997) provides some guidelines for estimating costs and benefits of a proposed restoration project; these procedures could also be used to compare and choose among several possible projects. Scarfe's (1997) cost/benefit analysis can be applied to the problem of choosing between two options for a hypothetical restoration project to be carried out on "Gambler's Creek."

The decision maker is considering two restoration options for a 540-m stretch of stream. The selected option will have the highest net present value (NPV), assuming a time horizon of 25 years and a "social" discount rate of 0.03, which reflects the need to value future resources relatively strongly. Both options involve the installation of large woody debris (LWD), with log volumes averaging 4 m^3 and costing about $400 each to install. Option 1, using 20 m^3/30 m of reach, will cost $35,800 now (Year 0), with additional follow-up work costing $15,000 in Year 1. Option 2, calling for 40 m^3/30 m of reach, will cost twice as much. Baseline assumptions, including the value of the two fish species and an angler-day, were established (Table 3).

The numbers of additional adults of each species expected each year as a result of the restoration were determined beginning in Year 4 (coho) and Year 5 (cutthroat, *O. clarki*) (Table 4). We used data from Scarfe's (1997) sample cost/benefit analysis for Option 1. An exponential regression fit to data relating numbers of juvenile coho to density of LWD (Koski 1992) provided an estimate of relative advantage for juveniles expected under Option 2. We assumed this advantage would carry through to the coho adults and would also apply to cutthroat. The coho are expected to be taken by the commercial fishery. The trout, to be caught by anglers, will yield an additional $40/angler-day to the local economy. For this situation, we expect 1 angler-day per trout.

Net present value (NPV) is simply the sum of the dollar values for each year, with future years discounted. For example, NPV for Option 1 is calculated as follows:

$$\text{NPV} = -\$35{,}000 - \$15{,}000/(1+.03)^1 + \$3904/(1+.03)^4 + (\$3904+\$2188)/(1+.03)^{5} + \cdots + (\$3904+\$2188)/(1+.03)^{25}$$

TABLE 3.–Parameters and baseline assumptions for cost/benefit analysis using the Gambler's Creek model.

Parameter	Baseline value
Value of 1 adult coho	$12.80
Value of 1 adult cutthroat	$22.50
Value of one angler-day	$40.00
Number angler-days/adult cutthroat	1.0
"Social" Discount rate	0.03

TABLE 4.–Costs and returns expected from the two restoration options for Gambler's Creek. Option 1: Install large woody debris (LWD) at a density of 20 m^3 30 m^{-1} reach unit; Option 2: Install LWD at 40 m^3 30 m^{-1} reach unit.

	Option 1	Option 2
Installation cost, Year 0	$35,800	$71,600
Installation cost, Year 1	$15,000	$30,000
Number of coho adults, starting in Year 4	305	508
Annual coho value	$3904 (= 305 * $12.80)	$6502 (= 508 * $12.80)
Number of cutthroat adults, starting in Year 5	35	58
Annual cutthroat value	$2188 (= 35 * [$22.50 + $40])	$3625 (= 58 * [$22.50 + $40])

Under these assumptions, the NPV of Option 1 is $33,626, while that of Option 2 is $38,920. Clearly, the decision maker should choose Option 2. Its higher returns, though not twice those of Option 1, more than offset its higher initial costs over the time horizon.

Accounting for Uncertainty at Gambler's Creek

Even in this simple example, the recommended restoration option may change when uncertainty is taken into account. An obvious uncertainty is the assumption that the predicted improved numbers of adult fish will continue unchanged over the next 25 years. The abundance of coho adults is subject to various oceanic factors, and both species may be negatively influenced in the stream environment by factors such as siltation or unfavorable water temperatures. To see how the possibility of a negative trend in survival to adulthood affects the NPV of each restoration option, let us cast this case as a decision analysis.

A decision analysis consists of three major components. The first two, (a) constructing a decision tree and (b) identifying the preferred management option, involve a well-defined set of steps, explained below. The third procedure of the decision analysis, (c) sensitivity analysis, is more open to the intuitions and concerns of those involved in the decision process, but it is no less important.

A. Construct the Decision Tree

A decision tree is a diagram that lays out neatly all the components and possible outcomes of the decision at hand. It is essentially a model of the decision to be made and its context. Constructing the tree is probably the most valuable part of the decision process, providing insight into the relationships and assumptions involved. Four steps are required to construct the tree:

Identify the management objective. For the Gambler's Creek case, the management objective is to maximize the net present value of salmonids that live or breed in the reach under restoration.

Identify possible management actions. The *management actions* (restoration options) under consideration are the two choices for density of large woody debris: Option 1 (20 m^3/30 m of reach), or Option 2 (40 m^3/30 m of reach).

Identify uncertain states of nature. A *state of nature* refers to any assumption that is important to the predicted outcomes of management actions. In any quantitative model of the outcome, the state of nature will include values of individual variables and parameters of quantitative relationships. The state of nature is never known with complete certainty in any biological or social system. Uncertainty may derive from inadequate information about the current state of nature. Alternatively, the real state of nature may be inherently so variable at the scale we can observe it that it would be hard to describe even with good information. In either case, uncertainty may be exacerbated if measurement tools are imperfect.

In the Gambler's Creek example, we identify one uncertain state of nature as a focus for the decision analysis: the possibility of a declining trend in expected additional adult returns. For simplicity, we will consider only two possible states, "Constant" and "Declining."

Additional uncertainties could easily be incorporated into the analysis, creating a decision tree with more branches. For example, one might hypothesize several possible relationships between numbers of juveniles and density of large woody debris.

Develop a model to specify outcomes. As in the "Gambler's Creek with no uncertainty" analysis above, the *outcome model* for the decision analysis follows the structure recommended by Scarfe (1997) for calculating the net present value of a restoration action. However, because more than one state of nature is possible, the model must provide separate answers for each state of nature under consideration. For the "Constant" state, we simply use the same number of predicted additional adults for each year of the time horizon. For the "Declining" state, we specify a function for the declining trend in additional adults: coho adult returns will decrease 2% per year, while trout adults would decrease by 1% per year.

Next, all this information is organized in a decision tree. In the Gambler's Creek decision tree (Figure 1), the choice between management options is represented by the square node at the far left. Following the line of an option toward the right, we pass through a round node representing the uncertain state of nature, where the path diverges. Each line leads to an outcome value, the NPV calculated for that combination of restoration option and state of nature.

Even without further analysis, questioning the assumption of constant survival is clearly pertinent. Option 2 has a higher NPV than Option 1 if survival is constant, but it is a poorer choice in the face of declining survival. There seems no clear preference for either option in the face of uncertainty about survival to adulthood. On what basis can we decide between the options?

B. Identify the Preferred Management Action

In order to proceed with the next component in the decision analysis, identifying the preferred management action, we must add a few more elements to the decision tree in Figure 1.

Devise a performance measure. A performance measure is a measurable quantity that indicates how well each management action will perform, given the array of states of nature under consideration. It is, of course, closely related to the management objective. For example, if the management objective of the Gambler's Creek example had been "Avoid any restoration action that could result in an NPV less than $15,000," then the performance measure would be the lowest NPV possible for each restoration option. Figure 1 clearly indicates that Option 2 would be unsuitable; its lowest possible NPV (in the decreasing state of nature) is less that $15,000.

In this example, the management objective was to "maximize the NPV of the restoration project." Given that objective, a good performance measure for a restoration option is its *expected value*. This is defined as the average of a restoration option's predicted outcomes over all states of

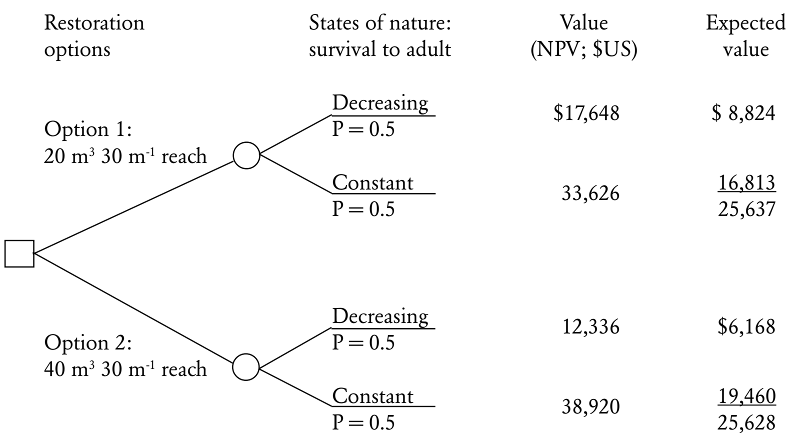

FIGURE 1.–Decision tree for the Gambler's Creek decision analysis example. In the "constant" state of nature, adult survival of the fish species is assumed constant over the 25-year time horizon. In the "decreasing" state of nature, coho salmon *Oncorhynchus kisutch* adult returns decrease by 2% per year, while trout *O. clarki* adult decrease by 1% per year. The probability initially assigned to each state of nature is 0.5, implying that if there were 10 waterways similar to Gambler's Creek, 5 of them would exhibit the "decreasing" state of nature. The value assigned to each outcome is the sum of its economic benefits over the time horizon minus costs of the restoration option. It is calculated as net present value (NPV) because future costs and benefits are discounted. Expected value is the product of each outcome's value and its probability of occurrence.

nature, with each outcome weighted by the chance that it will occur. Thus, to calculate the weighted average, we must quantify the likelihood that each possible state of nature will actually occur.

Estimate probability for each state of nature. The chance of a state of nature occurring, its *probability,* can be assigned in one of several ways. If enough cases exist, probability can be predicted from its past frequency. Where the past frequency is not available, but data exist that are consistent with more than one state of nature, Bayesian statistical analysis can assign probabilities to each state of nature under consideration. Fundamentals of Bayesian statistical analysis are presented in Ellison (1996) and Hilborn and Mangel (1997).

Often, however, the probability of a state of nature in a decision analysis must be based on a more subjective assessment, reflecting the decision-maker's confidence in its occurrence. In this case, some analysts recommend using the opinions of experts. Asking experts to assess the probability of a hypothesis requires attention to both the mathematics (Cooke 1991) and the psychology (Anderson 1998; Gigerenzer 2000) of subjective probability. For example, people make predictable errors when asked for a decimal probability but give more accurate estimates when asked to estimate the same probability as a frequency that would be observed if there were many examples of the uncertain system.

Though uncertainty about the state of nature can be treated as a set of hypotheses, it is important to understand that familiar "classical" statistical tests such as analysis of variance do *not* provide the probabilities required by decision analysis. The P-values of classical statistical tests describe the probability of observing the data at hand *if* a particular hypothesis were true, but they tell us nothing about the likelihood that the hypothesis (or state of nature) itself is, or will be, true.

Calculate expected value for each outcome. Probabilities for the states of nature appear on the branches of the decision tree in Figure 1. The equal probabilities reflect a situation in which the decision maker believes that the two states of nature are equally likely; for example, among 10 similar populations, survival to adulthood would decline in 5 while it would be constant in the other 5. The last column shows the expected value of each outcome, which is the product of its net present value and its decimal probability of occurrence.

Compare the management options. The expected values of each restoration option across both states of nature are the sums in the last column of Figure 1. This is the performance measure required to compare the two options. It suggests that the two options' performances are expected to be very similar, with a slight preference for Option 1. Under these circumstances, a decision maker might reasonably allow considerations other than expected NPV to enter into the decision. Thus, including uncertainty in the analysis has produced a recommendation different from the deterministic analysis above, where Option 2 was clearly to be preferred.

C. Sensitivity Analysis

The weak recommendation for Option 1 in the Gambler's Creek decision analysis at this point should be viewed with healthy skepticism. Even this simple example includes a number of untested assumptions, some more questionable than others. Sensitivity analysis addresses the question, "How would the recommendation change if those assumptions were altered?"

Several assumptions in the Gambler's Creek example seem worthwhile examining in this light. First, in the "baseline" scenario presented above, the two states of nature were assumed equally likely to occur. What if the decision maker had information suggesting other probabilities? Different assumptions about the probability of constant survival to adulthood will affect the preferred option (Figure 2). We have subtracted the expected NPV of Option 2 from that of Option 1 to produce the "Difference" plotted on the Y-axis in Figure 2. Where Difference is positive, Option 1 is preferred because its NPV is larger, and where Difference is negative, Option 2 is preferred. The recommended action is clearly sensitive to assumptions about the probabilities. However, suppose the decision

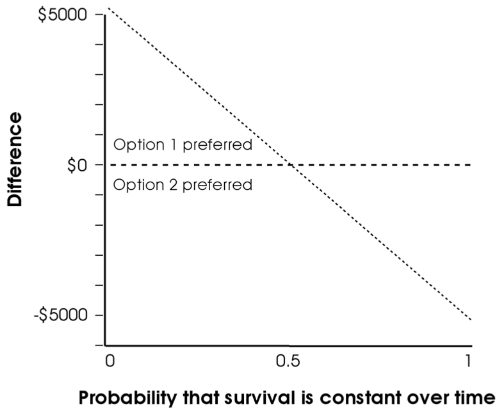

FIGURE 2.—Sensitivity analysis: The effect of the probability of future trends in adult returns on the recommended density of large woody debris. The Y-axis is the difference between the expected value of Option 1 and that of Option 2; where it is positive, Option 1 is preferred.

maker is moderately sure a declining trend will occur. In other words, from experience in this area, the decision maker feels that if fish populations were observed in 10 waterways like Gambler's Creek, constant survival would be evident in fewer than half the waterways, suggesting that the probability of constant survival is ≤0.4. In this case, the exact probabilities are not a concern, since Option 1 is preferred for any probability in this region. Similarly, any degree of moderate to strong confidence in constant survival to adulthood (P ≥0.6) recommends Option 2.

In another sensitivity analysis, we examined the baseline assumption that each adult trout would produce 1 angler-day ($40) of recreational revenue. Any inaccuracy in the predicted angler-days-per-fish can affect the recommended restoration option dramatically. If the value is as high as 1.5 angler-days-per-fish, Option 2 becomes favored; the difference in expected NPV is strongly negative (-$5,690). If it is as low as 0.5, Option 1 is definitely preferred; the difference in expected NPV is positive ($5,707). In this case, the sensitivity analysis indicates a rather urgent research priority concerning human response to the resource.

Sensitivity analysis is essential to decision analysis. In addition to identifying research priorities, exercising the decision model (the decision tree) and its components can give decision makers a better understanding for the context of the decision and why particular actions are preferred in some circumstances. Agreeing on a model and developing a sense of its behavior can be especially helpful if several parties are involved in the decision. People may disagree on assumptions or objectives, but if they can see that the recommended action is unaffected by those differing assumptions, it becomes easier to agree on a course of action (Maguire and Boiney 1994). A dramatic example of this effect is described by Peters and Marmorek (2001). The PATH is a large decision-analysis model designed to evaluate alternative management actions for the Columbia River watershed. Sensitivity analysis showed that only 3 of the 11 uncertainties analyzed by the PATH would have any effect on the ranking of the management actions under consideration. This result enabled participants in its development to focus their efforts and discussions on the three important uncertainties.

In summary, the simple Gambler's Creek example points up several advantages of a formal decision analysis. First, it shows how including uncertainty changes the decision process from the deterministic methods often used. Second, we have seen that selecting the objective and performance measure is critically important. Third, sensitivity analysis can help focus research effort where it is most needed. Fourth, decision analysis can help to structure discussions among stakeholders, identifying differences and similarities in their points of view and catalyzing creative suggestions for new management options (Maguire and Boiney 1994). Finally, decision analysis gives a view of the whole decision process and clarifies its context even if information is missing, the decision makers do not complete all the steps, or moral or ethical concerns prevent the recommended action from being carried out. Bayesian decision analysis can also be used to analyze more complex decision problems, such as those involving both multiple uncertainties and multiple decision points.

Formalizing the decision process is especially helpful when the decision involves risk–the possibility of a major negative outcome (Harwood 2000). People have trouble making decisions in risk situations, especially when there is a small probability of incurring a very large cost. Our intuitive estimates of the probabilities involved and the costs of the outcomes can be biased (Tversky and Kahneman 1974) and emotions, such as dread and mistrust, may interfere with rational consideration of options (Slovic 2000). Constructing a decision tree can promote clearer understanding in these situations by separating the two components of risk: the negative outcome itself, and its chance of occurrence. It also may allow the accompanying emotions to find controlled expression in the statements of objectives and performance measures.

A good decision strategy for a restoration project will not always produce the most desirable outcome in the end. Any decision made in the face of uncertainty is a gamble, and the best gambler sometimes loses. This is especially true if the plan is a static one where few resources are allocated to monitoring and review of the initial decision. However, over the long run, management decisions will prove robust and defensible when they proceed from a clear, consistent decision process, despite the occasional negative outcome.

Cedar River: A Passive Adaptive Management Plan

Scientific evidence is often insufficient to justify firm quantitative predictions about the effects of large restoration plans or their likelihood of success. Nevertheless, a passive adaptive approach to selection and timing of component projects can allow the plan to move forward efficiently in the face of multiple uncertainties. We illustrate this process using the example of the action plan for the Lower Cedar Basin (King County 1998), demonstrating how an adaptive decision maker might place priorities on these projects despite seriously incomplete information about their outcomes. These priorities lead naturally to the possibility of passive adaptive management, with its benefits of improved information and flexible response at future decision points.

King County proposed a watershed management plan to resolve hazardous flooding, protect and restore aquatic habitats, and maintain water quality of the Cedar River Basin (King County 1998). The Cedar River, which flows into Lake Washington near Seattle, Washington, has experienced loss of river habitats in the lower basin and declines in salmon populations. The plan proposes over 70 individual projects and presents a difficult decision problem: given limited resources, how should we place priorities on the projects?

Setting priorities requires predicting the likely effects of implementing the projects. In addition to uncertainties about the numbers of adults returning, the numbers of fry and smolts produced are variable and uncertain. Predictions in the Cedar River plan were largely based on the assumptions and biostandards (estimates of abundance or output) of Koning and Keeley (1997). The estimates were intended to be conservative. For example, some reasonable production estimates were divided by 2, and some costs were intentionally overestimated. This proposal suggested average, high, and low values for juvenile production although only the average estimates were used in the summaries of cost-per-juvenile for each project. Often, owing to gaps in the data, high and low estimates were obtained by procedures such as multiplying the average estimate by the coefficient of variation for related data. Some additional uncertainties were not quantified: for example, if data for a particular stream were not available, data for a similar stream were used. Despite these uncertainties, it is still possible to rank projects and to decide which ones should be attempted first as part of a passive adaptive management scheme.

Assessing the Efficacy of the Proposed Restoration Projects

The Cedar River proposal provided low, average, and high estimates for fry or smolt production for sockeye *O. nerka*, coho, and chinook *O. tshawytscha* salmon, and steelhead *O. mykiss* and cutthroat in mainstem, valley floor, and tributary habitats (King County 1998, Appendix E: Estimation of salmonid production potential and costs of fish habitat restoration opportunities). For this example, we analyzed the predicted effects of mainstem projects upon production of chinook smolts (listed under the ESA in 1999). The proposal predicted the costs and annual production potential (APP) of smolts for each project. We used the low/average and average/high ratios for mainstem habitat to produce "low" and "high" estimates of APP for chinook.

For each mainstem project, we used the estimates of 50-year total costs to obtain a price-per-chinook-smolt produced based on the average estimated annual smolt production. Assuming that the projects would be implemented in order of increasing price per fish, we computed cumulative costs and numbers of smolts, using low, moderate, and high estimates for production. Table 5 lists project numbers, together with price per smolts and cumulative cost, for average production.

An Adaptive Plan for Implementing the Projects

If we assume the projects are to be undertaken in order of increasing price per smolt, the expected cumulative smolt production increases as a function of cumulative costs but with diminishing marginal returns (Figure 3). The pattern is similar for low (dashed line), average (solid line), and high (dotted line) levels of productivity. The projects corresponding with cumulative costs above $30 million show a relatively small return-per-unit-invested, a result consistent with the high price per smolt for those projects (Table 5). At higher cumulative costs, there is a wide gap between the average and the upper curves and a smaller gap between the low and the average estimates. Though we present only the predicted effects of projects in the river's mainstem upon chinook salmon, other species included in the Cedar River restoration proposal showed similar patterns.

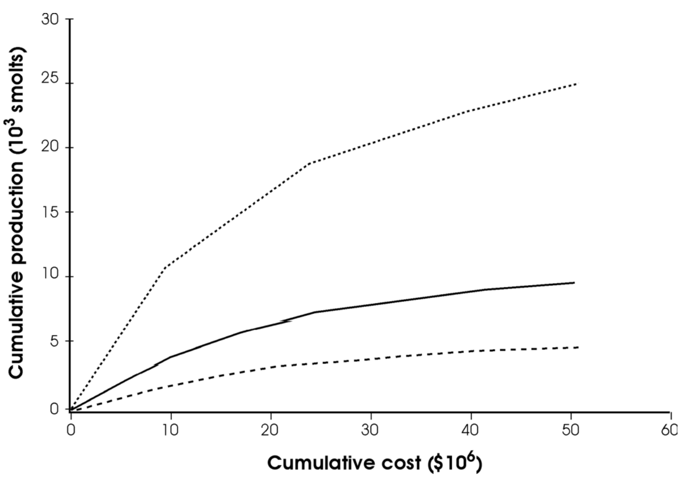

FIGURE 3.–Cumulative chinook *O. tshawtyscha* smolt production vs. cumulative cost for proposed restoration projects on the Lower Cedar River, King County, Washington. The lower dashed line and the upper dotted line correspond respectively with low and high estimates for production potential (based on data from King County 1998).

TABLE 5.–Chinook projects proposed for the Cedar River mainstem, ranked in increasing order of price per smolt ($\$10^3$ smolt year^{-1}). Cumulative costs ($\$10^6$) assume the projects are implemented in rank order. The site references identify the projects described in King County (1998).

Project rank (site number)	Price	Cumulative cost
1. (70)	1.5	1.2
2. (73)	2.3	1.8
3. (74)	2.6	9.6
4. (66)	3.6	10.8
5. (71)	3.7	13.1
6. (69)	3.7	13.9
7. (77)	4.7	20.6
8. (76)	4.7	21.7
9. (75)	5.9	23.7
10. (67)	8.3	35.5
11. (68)	12.1	39.2
12. (72)	21.4	50.7

In the case of the chinook (Figure 3), the low production curve indicates that an expenditure of approximately $40 million might be required to ensure annual production of 4,000 smolts. The high production curve suggests that such production might be achieved with a much lower expenditure of $2 million. How much should be budgeted? If $40 million is spent, this might decrease funds to carry out projects that would benefit other species. If only $2 million is spent, it might have only a small effect on chinook production. Suppose the goal is 5,000 smolts per annum. In that case, perhaps no expenditure would achieve the goal, and perhaps $5 million would suffice. The scientific evidence cannot distinguish among these alternatives.

Implications of the Uncertainty

Koning and Keeley (1997) discuss many reasons for caution when using biostandards to predict responses to specific watershed restoration activities. Upslope impacts and instream bottlenecks, variation in stream temperature and nutrient levels, variation in ocean survival, and different levels of restoration effort all can be expected to add uncertainty to predicted responses. Moreover, responses reported may be biased toward positive values because projects that do not enhance fish production may not be published. Nevertheless, Koning and Keeley (1997) suggest that the biostandards they report may be useful as standards against which to compare post-restoration results, with the expectation that predictions will improve as collective experience with restoration accumulates.

One additional complication is a conflict between the inflow regimes for the Cedar River that are required for chinook fry survival and the water supply for King County and the City of Seattle. This conflict is exacerbated by our lack of information about the effects of various inflow regimes on the fish. There is good reason to believe that inflow is important, but the magnitude of the effect and the ranges of inflows that may be adequate are still unclear. Periods of high flow can also complicate the analysis, because flood flows and scour have negative impacts on chinook survival. Off-channel spawning areas may prove more valuable than in-channel improvements under these circumstances. In all likelihood, conflicts over water use will be decided in the courts or in a compromise among the interested parties, but that process may not answer the question of what the effects of the final decision are likely to be. In principle this is a scientific question, but extensive investigation has not provided a generally accepted answer.

Since the chinook stock analyzed here is listed under the ESA, special consideration must be given to its survival and maintenance. One of the rules formulated to implement the ESA is the "No Surprises" provision, whereby the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) are required to provide a list of mitigation measures to be carried out by the City of Seattle at an agreed-upon cost. These measures may not be altered unless "unforeseen circumstances" arise, which are interpreted to be rare circumstances beyond human control, such as earthquakes or unusual flooding. The agencies are also required to identify "changed circumstances" that may reasonably be anticipated and to prescribe the measures that will be taken under these circumstances. The distinction between "unforeseen circumstances" and "changed circumstances" is that a reasonable person might be able to anticipate and plan for the latter.

In the light of the large gaps revealed in our ability to predict chinook smolt production, consider the burden this places upon the regulatory agencies. A reasonable person who is confronted with the large divergence between the upper and lower curves in Figure 3 might conclude that the middle curve is a suitable compromise. However, there is no assurance that production will actually follow the middle curve. A prudent and cautious person might conclude that we should behave as if the lower curve might be expected under "changed circumstances," but that curve portrays just one of many possible unfavorable "changed circumstances." There is no basis for generalizing from it, and it does not represent a limit on the system's possible behavior. Different interest groups could argue that any decision is a gamble and may ask for the odds favoring one outcome or another. Many reasonable interpretations may be assigned to the inconclusive scientific evidence, and they may lead to large divergences in policy.

In view of the King County action plan's many unanswered questions, it is prudent to adopt an incremental approach to large restoration projects. Figure 3 clearly shows that all projects in the Cedar River plan should not be implemented at once. However, despite inadequate scientific evidence, it is possible to order the projects as in Table 5 and develop a passive adaptive management plan. Such a plan might specify a portion of the budget for initially implementing the most cost-effective projects and for monitoring. The planners would also allocate funding toward future decision points, when data from the initial projects would be analyzed, giving the decision makers an idea of the trajectory that best described their cumulative efforts (e.g., high, average, or low production, or some curve in between). Additional projects could then be implemented appropriately on the basis of that new information.

How large should the budget for monitoring be? One might attempt to estimate the costs and possible benefits of monitoring, but clearly additional uncertainties will enter. The size of the benefits realized can only be calculated after the resulting policy has been implemented and monitored. Thereafter, we can expect the economic impact to change over time. The addition of a few tens of thousands of smolts may be important when escapements are critically low, possibly preventing extinction of the population, but once the population has recovered, that same number of additional smolts will scarcely be detectable. Even if one were able to perform a rigorous scientific assessment, the actual budgetary decisions will probably be determined intuitively or politically. We have no easy solution to this problem.

Adaptive Management and Evolutionary Decision Making in the Basinwide Salmon Recovery Strategy for the Columbia River Drainage

Over the last 150 years, salmon within the Columbia River drainage, particularly the Snake River, have declined precipitously, so that several evolutionarily significant units (ESUs) of steelhead, and chinook, and sockeye salmon are listed under the ESA. This decline is associated with a combination of dams, water withdrawal, numerous other forms of habitat degradation, harvesting, hatcheries introducing disease and competitors, cyclically poor ocean conditions, and predation by native (northern pikeminnow *Ptychocheilus oregonensis*) and non-native fishes (walleye *Stizostedion vitreum*, various centrarchids).

In response to these challenges, federal authorities concerned with the watershed ("The Federal Caucus") have developed a comprehensive recovery plan for the affected salmonids: the Basinwide Salmon Recovery Strategy ("Basinwide Strategy"; Federal Caucus 2000). One of the most contentious issues has been the suggestion that breaching the Snake River dams is essential to the recovery of salmon stocks on that river. After considerable discussion on this and other proposed recovery options, the Basinwide Strategy, together with the December 2000 Biological Opinion of the National Marine Fisheries Service (NMFS 2000), set the near-term course for research and actions intended to restore endangered salmon populations. The Basinwide Strategy assumes multiple goals, including the following:

- conserve species (halting downward trends in listed ESUs within 5 to 10 years),
- conserve ecosystems (emphasizing estuarine, spawning, and rearing habitat),
- balance the needs of other fish and wildlife,
- assure tribal fishing rights and provide non-tribal fishing opportunities,
- minimize adverse socio-economic effects in general,
- protect historical properties, and
- preserve the resources needed for tribal cultures.

The Basinwide Strategy (Federal Caucus 2000) prescribes continued dam operation on the Columbia River and its tributaries, with management adjusted to lessen impact on fish. On the basis of analyses recommending improvements in first-year survivorship, the plan emphasizes restoration of spawning, rearing, and estuarine habitats. It also calls for hatchery reforms intended to support wild populations.

The Basinwide Strategy recognizes the importance of reviewing progress and sharing information. The agencies carrying out the Strategy will be required to monitor implementation and results, with progress reports at 3, 5, and 8 years. Moreover, the Basinwide Strategy and Biological Opinion prescribe standardized indicator variables and the use of common databases to facilitate the sharing of information.

The progress reports at Years 3, 5, and 8 constitute decision points as well as opportunities for review. In particular, if stock trends continue downward at the end of this period, dam breaching will be reconsidered as a restoration option. Thus, the Basinwide Strategy will set in motion a complex ongoing management process with multiple decision points. Despite many unanswered questions, the Basinwide Strategy must proceed, owing to the urgent threat to the various listed populations.

The scope of these plans, their mandate to monitor and evaluate progress, the unanswered questions, and the multiple conflicting goals all suggest that forms of adaptive decision making will continue to be important as the Basinwide Strategy unfolds. In the following text, we discuss the potential for some recommended management actions to provide opportunities for evolutionary problem solving and for passive and active adaptive management.

Adaptive Management and the Basinwide Strategy

The Basinwide Salmon Recovery Strategy (Federal Caucus 2000) calls explicitly for the application of adaptive management. The report specifies some components of passive and active adaptive management (e.g., identification of uncertainties, monitoring, and decision points). Elements of experimental design are mentioned, such as the Before-After-Control-Impact (BACI) experimental plan (Underwood 1991, 1994) and statistical power analysis, which evaluates the chance of detecting the effect of an experimental treatment when it is really present.

However, adaptive management does not seem to infuse the framework of the whole recovery plan. For example, the flow diagram of the Basinwide Salmon Recovery Strategy places "adaptive management" as the last step in the implementation of performance standards ("Results: Monitor and evaluate; adaptive management"; Federal Caucus 2000, p. 5). In addition, some aspects of adaptive management seem to be understated in this document. For example, learning about the ecosystem is not one of the stated primary goals. Though there is discussion about relationships among the many institutions involved, the Basinwide Strategy and Biological Opinion do not specify a comprehensive institutional structure mandated to assign spatial and temporal variation in practice. Wise experimentation will also require that decision makers feel confident about hypothesis testing and experimental design in management contexts. As a bare minimum, practitioners of adaptive management ought to be familiar with the concepts of randomization, replication, and statistical power. Examples and discussion of these experimental design "basics" are largely missing from the Basinwide Strategy and Biological Opinion.

If the Basinwide Strategy is to be implemented successfully, elements of adaptive management should appear throughout the flow of management and research activities. Practitioners at every stage of the restoration process should be educated about the adaptive management framework and learning goals. For example, putting passive or active adaptive management into action will require several activities before management actions and monitoring even begin, such as identifying hypotheses to test, consulting with statisticians, estimating variance of the variables to be monitored, and assigning treatments to sites.

Active adaptive management, especially, demands institutional arrangements that support decision makers as they experiment with various options. The reviews mandated for Years 5 and 8, with the possibility of agencies receiving a "failure" rating, should be modified to provide leeway for agencies that purposely vary practice for experimental reasons (Gunderson 1999). A timeframe of 5 to 8 years may also be too short for estimating some important variables. In sum, these reviews do not seem to be structured to facilitate either successful experimentation or the essential social elements of science: curiosity, credit, and checking (Hull 1988, 2001).

In addition, adaptive management, whether passive or active, requires clearly defined goals and objectives. Therefore, any adaptive management process will need to be based on objectives derived from an internally coherent subset of the seven general goals listed above, and hypotheses to be tested should relate to those objectives. Where this is not possible, explicitly structuring the system to facilitate evolutionary problem solving and improvement in practice may be more appropriate.

Possible Management Actions and Questions to Address

The list of possible management actions proposed to rebuild the salmon includes the following:

- transportation of fish around dams in barges,
- flow augmentation to manage water temperature and to speed fish passage downstream past predators,
- restoration of habitat,
- hatcheries to supplement wild production,
- reducing harvest levels, and
- breaching dams to return the river to a more natural condition.

These management options, if implemented, will probably interact with one another. However, separating them to the extent possible may provide opportunities for adaptive management by producing arenas of action that are at least partly bounded. Thus, structuring this large restoration problem along the lines of the "Four H's" (habitat, hatcheries, hydropower, and harvest) is more than merely a clever mnemonic device.

Associated with each management option is a range of assumptions about how that management option affects fish. The models developed to analyze the restoration problem differ in their assumptions and emphasis (Chapter 10, this volume; Kareiva et al. 2000; Mann and Plummer 2000; Deriso et al. 2001; Peters et al. 2001; Peters and Marmorek 2001). Despite their differences, they jointly emphasize important unanswered questions that might be addressed via adaptive management.

Some uncertainties are as follows:

1. How well do migrating fish survive through the dam system and individual dams?
2. How does augmented flow affect fish survival?
3. How well do transported fish survive? Does transportation affect their survival after they are returned to the river?
4. How well do adults survive upstream migration?
5. What is the impact of hatchery operations on wild fish?
6. How will dam breaching affect downstream and upstream passage?
7. How will dam breaching influence sediment budget?

Sensitivity analyses on the models have suggested priorities for answering the above questions, and those priorities in turn dictate whether active or passive adaptive management can contribute to learning. For example, the PATH model (Marmorek et al. 1998) recommends dam breaching as the best action under a wide range of assumptions about other variables. This suggests that learning needs to be focused urgently on dam breaching (the last two questions). In contrast, the CRI model (Cumulative Risk Initiative, Kareiva et al. 2000) recommends actions to restore habitat used by the fish in their first year of life, assuming continued operation of dams and hatcheries, suggesting that the first five questions should be given priority. To what extent will adaptive management be useful under each of these priority rankings for the questions?

Potential for Adaptive Decision Making

Transportation of Juveniles Around Dams

Questions about transport might be explored by active adaptive management. As an experimental treatment, transport could easily be modified or turned on and off. As a management choice, however, the latter manipulation carries a risk of reducing the experimental stock's chance of long-term survival and recovery below that expected with the status quo, if survival among non-transported fish is poor (Peters and Marmorek 2000).

In terms of experimental design, the best comparisons are pairings between transported and untransported fish of the same species in the same year over the same series of dams. A comparison of transported and natural passage hatchery fish along undammed rivers might also contribute to the estimate of delayed mortality from transportation (Paine et al. 2000). If transport is applied in an all-or-nothing way along a particular river, such a paired design is not possible. In that case, comparisons could be made spatially between dam series within the same year, or temporally between years along the same series of dams. In either case, these unpaired designs will require larger numbers of dam series for spatial comparisons or years for temporal comparisons.

Managers could also learn about transport by passive adaptive management or an evolutionary approach, but the learning will take longer. Over time and across projects, there will be enough unintended variability in the transportation process and its context that managers may identify more or less successful circumstances by taking advantage of the monitoring program, decision points, and common databases prescribed by the Basinwide Recovery Strategy.

Flow Augmentation

Questions about flow augmentation also present some potential for active adaptive management. Flow across an individual dam can be manipulated, and ideally managers could implement spatial variation by allowing high flows at some dams and low flows at others while monitoring downstream (and upstream) passage survival through each facility. However, spatial variation is difficult to achieve because the dams are not independent. When flow is augmented across one dam, the water soon arrives at the next dam, necessitating a corresponding increase in its flow as well. Moreover, years of poor snowpack severely restrict flow options. The limited snowpack of the winter of 2000–2001, for example, led to the declaration of a "power emergency," which suspended the operational requirements of the Biological Opinion. Such events can seriously impede any experimental schedule for manipulating flows. The whole watershed can be affected by years of unusually high snowpack as well (Chapter 2, this volume).

These same considerations apply to passive adaptive management. Any stretch of 10 years or so will undoubtedly reveal plenty of variation in flow regimes, both intended and unintended. Some conclusions can be drawn from a review of monitored indicators in relationship to flow, but it will be hard to filter out confounding variables. For example, a hot summer may result in both higher ambient temperatures and changes in flow regime to meet power demands.

Flow augmentation has significant economic consequences and thus will usually occur in an environment of irreducible goal conflicts. In such an environment, evolutionary prototyping may be more successful to the extent that innovative approaches to flow management can be divided into separate cases or prototypes.

In experimental design, it is easier to learn from a treatment that is expected to affect only a specific dependent variable of interest. Unfortunately, flow augmentation is a relatively crude experimental tool. Change in flow regime can affect survival before, during, and possibly after passage through the system of dams and reservoirs. Therefore, stage-specific estimates of survival will be needed to distinguish how flow regimes influence mortality in each of those time periods.

Restoration of Habitat

The Basinwide Strategy proposes major initiatives in habitat restoration and preservation in the estuary, mainstem, and tributaries of the Columbia River Basin. The variety of actions and geographical divisions present many possibilities for adaptive management. For example, though the estuary and mainstem are not easily divided, tributaries offer numerous, relatively independent spatial replicates. Where sample size is low, as is the case with most ecosystem-scale experiments, adding even a few replicates to each experimental group can greatly increase the statistical power of an experiment and the reliability of inferences drawn from it. This multiplicity has a disadvantage, however. Owing to the enormous geographic area, different state and federal jurisdictions will be involved in any large-scale experimentation, complicating the coordination needed and introducing the possibility that experimental habitat manipulations may not be carried out as planned.

Habitat restoration also has potential for both passive adaptive management and evolutionary improvement in practice. These processes depend heavily on a well-designed temporal monitoring scheme. Some actions, such as improving tributary flows, will probably produce results quickly; others, such as restoring riparian plant communities, may take years. The proposed performance measures and three-tiered monitoring scheme of the Basinwide Strategy will be particularly important here. They have been selected to provide information at several spatial and temporal scales. In addition, interim performance measures such as number of hectares of habitat treated will provide some information until habitats develop sufficiently for more detailed performance measures.

Of all the actions discussed here, habitat restoration may provide the best opportunities for adaptive management as the Basinwide Strategy unfolds. The biggest problem will likely be the sheer volume and variety of information produced by many projects. It is almost impossible to overemphasize the importance of managing that information so it can be efficiently shared, and results understood and used by decision makers and the public as well as scientists. The Strategy acknowledges the need for standardized data collection and centralized databases. It is also important to take advantage of indicators that are already standardized and in use elsewhere. For example, Paine et al. (2000) suggest adopting the IUCN's well-established criteria to classify extinction risk.

The Basinwide Strategy and Biological Opinion propose to coordinate the application of results by placing them in a theoretical framework based on matrix population models for the ESUs. Matrix models are not the only valid method of analyzing complex population dynamics, but they do present a distinct advantage in this case. They are relatively easy for scientists to share and for interested non-scientists to understand; this is evident from the quick positive response of decision makers to the matrix model developed by the Cumulative Risk Initiative.

Hatcheries

Hatchery production can be varied in space and time, and the Basinwide Strategy explicitly suggests implementing, in an adaptive management framework, a variety of non-traditional hatchery practices intended to help, or avoid harm to, natural fish populations. This framework could constitute active or passive adaptive management. For example, Peters and Marmorek (2000) simulated designs for an experiment to manipulate the number and timing of hatchery steelhead releases. They conclude that such an experiment could provide information about the direction of change in chinook salmon survival within a decade. However, there are some key concerns about the past effects of hatcheries; these effects are not amenable to experimental treatment or to assessment at early decision points, and they may be difficult to reverse. For example, hatcheries may have introduced diseases and changed the genetic makeup of wild stocks. These impacts cannot be manipulated in a short time scale and on a small spatial scale, so hatcheries provide little scope for adaptive management with respect to these hypotheses.

Several possibilities for improving hatchery practice face problems deriving from incompatible biological and social objectives. These may best be ameliorated by an evolutionary approach to problem solving. For example, how can the selective harvest of hatchery fish in a mixed fishery be made more discriminating? Various innovations are possible, such as better net design, run timing, and education of fishermen (Lackey 2000). Hatcheries are to some extent bounded units, and their managers will undoubtedly try out varying approaches to solving the mixed fishery problem. Therefore, it might be appropriate to develop an institutional structure that would promote innovation, diffusion of results, and adaptation, with the intention of facilitating evolutionary improvement in hatchery operation and harvest methods.

Harvest Levels

The Basinwide Strategy observes that harvest rates are already low, tribal harvest is a permanent requirement, and further decrease in harvest is unlikely to have a major effect on the dynamics of listed Snake River populations (Kareiva 2000). Given these assumptions, the Strategy does not prescribe large manipulations in harvest levels. Instead, the proposed actions are intended to make existing harvest practices more selective and less harmful to listed ESUs. The most seriously depleted stocks, those of Snake River, are harvested over a wide geographic range, including outside and inside the Columbia River Basin. There is little harvesting once the fish leave the Columbia and enter the Snake, and thus little chance of precisely controlling the harvest of Snake River stocks independently of other stocks or for spatial replications within the Snake system. Thus, while harvest rates can be manipulated to some extent, there are many barriers to implementing a successful active or passive adaptive management framework.

As with flow regimes and dam breaching, the most serious barrier to adaptive management of harvest is probably conflicting goals. It is difficult to persuade people who depend economically on fishing to give up their economic well-being in favor of learning. The presence of multiple goals and a general shared interest in improving practice does not guarantee that an evolutionary approach will be suitable here, however. Unlike flow regimes and dam removal, harvest practices may not divide easily into bounded "cases," and it may be difficult to persuade groups of harvesters to try innovations unless they have some sense of ownership of the situation. Thus, arrangements to facilitate prototyping will probably be most successful where harvesters occur in somewhat isolated groups or terminal fisheries, as some tribal harvesters do.

Dam Breaching

Dam breaching provides some potential for active adaptive management. The most likely manipulation is removal of the four Snake River dams. Though not truly an "experiment," this intervention could be treated as a case study similar to the flooding of the Grand Canyon (Collier 1997). Appropriate analysis of such a before-after design can detect a large effect size fairly efficiently (Peters and Marmorek 2000). However, case studies such as this are vulnerable to confounding variables that change simultaneously with the purposeful manipulation. Alternatively, spatial controls might be arranged outside the Snake River system, bringing the advantages of a BACI design to the analysis.

Passive adaptive management of dam removal would be difficult to undertake because actions at later decision points under the passive adaptive framework will probably be severely restricted. Most of the steps involved in dam removal are not easily reversible or adjustable at future decision points. In addition, dam removal is sufficiently disruptive to both river habitats and human economies that it will be difficult to justify spreading the actions over time to allow for multiple decision points.

Dam removal is nearly always associated with multiple, conflicting goals, which suggests that this problem could be a candidate for a well-planned evolutionary approach. The slated removals of dams that are no longer cost-effective elsewhere in the Pacific Northwest (for example, the Condit, Wapatox, and Marmot dams) might provide some valuable case studies, though on a smaller scale. These dam removals exhibit an important characteristic of prototypes in evolutionary problem solving–namely, their relatively low political profile (Brunner and Clark 1997). Faced with conflicting objectives (e.g., restoring the river environment and minimizing impact on humans), managers are more likely to be able to try varied approaches on cases that do not command too much political attention.

Rummaging in the Decision Tool Box

Adaptive management, especially active adaptive management, is often recommended as a preferred strategy for implementing management or restoration decisions in the face of uncertainty. However, adaptive management has not been implemented on a wide scale for a variety of reasons. The logistical difficulties can be daunting: Hilborn (1992) argues that the vast majority of fisheries management decisions are never evaluated, so it is difficult to learn from their outcomes and adjust management actions adaptively.

A more serious difficulty, however, is the failure of proponents of adaptive management to account for social variables and the institutions involved (Walters 1997; Gunderson 1999; Lee 1999). However logical and compelling adaptive management may be, it is hard to transform resource managers into part-time scientists without the internal social context of science to support them. Hull (1988, p. 301) concludes, "Striving after truth for its own sake in the absence of the social structure of science that has grown up to foster this search is about as effective as Don Quixote's efforts to help humanity." In addition to the essential elements of the social context of science (curiosity, credit, and checking described above), Hull (1988, 2001) suggests that the "demic structure" of science is also critically important to the evolution of ideas and practice: Productive scientists tend to operate within research groups including both senior scientists and students. Members of the research groups may cooperate extensively, taking advantage of complementary skills and different points of view. The presence in a research group of members at different stages in their careers ensures a variety of styles and timeframes for communication and relationships with other groups working in the same area.

Fields that depend heavily on statistical analysis, such as medicine, psychology, and applied ecology, face an additional challenge with respect to internal social arrangements. The particular style of statistical practice used in a field of science is part of the culture of that field. Seen in the cultural context, statistical practice is a particularly complex set of behavioral rules that are learned and maintained only through intensive training and constant social reinforcement. As with many cultural practices, rational conclusions about optimal practices in statistics do not always result in prompt compliance by the community. For example, Sedlmeier and Gigerenzer (1989) document the failure of researchers in psychology to improve the statistical power of their experiments since the first published observation, nearly 40 years ago, that most studies in that field were deficient in statistical power. Sedlmeier and Gigerenzer's (1989) explanation for this failure involved both the history of social and intellectual relationships among the early statisticians, and the history and authority structure of academic psychology. Advocates of active adaptive management might benefit from a similar cultural analysis as they call for the optimization of experimental design (Walters 1986; Peters and Marmorek 2000). Understanding and manipulating the relevant social relationships, authority structures, and cultural processes may do more to facilitate improved experimentation than any amount of rational argument or fine tuning of experimental design.

The process of optimizing experimental design brings into focus the tradeoff between accuracy and effort (or time) for active adaptive management as well. How much planning time should be dedicated to finding the best experimental design, if a merely adequate design will give adequate answers sooner? The utility of our species' "fast and frugal" intuitive decision methods (Gigerenzer et al. 1999), the urgency of many conservation problems, the slow response time of most ecosystems, and inevitable financial limitations all remind us that time and cost are worthy opponents to accuracy. Nonetheless, the accuracy of inferences may improve despite severe limits on time and effort if the internal social arrangements of adaptive management applications are explicitly structured so as to promote the social dynamics characteristic of science (curiosity, credit, and checking).

Aside from the problems of social context, there are a number of good reasons why adaptive management is not always preferable to a static decision strategy. First, monitoring may be so expensive that it is prohibitive or the potential economic benefits of the projects may be so high even given the uncertainty that there is no point in diverting much of the budget to monitoring and learning. Second, if monitoring seems unlikely to resolve the uncertainty about the states of nature, it will provide no better basis for choice among management options at future decision points. Third, it may take so long to discriminate between the efficacy of different management options that irreversible outcomes intervene (extinction, for example), making the choice at later decision points irrelevant.

Similarly, active adaptive plans are not always preferable to passive ones. Indeed, it appears that active adaptive plans are usually better only when there is considerable potential for spatial replication and rapid learning. A BACI experimental plan can be used in situations where there are only one experimental site and one or more controls, but inferences based on this design may still be confounded. A well-considered passive adaptive plan may be simpler and cheaper to implement and provide equally satisfactory information in the long run.

Evolutionary problem solving will not usually produce quick results, but it has much intuitive appeal and it can take various forms. For example, noting that conditions for rigorous adaptive management are often hard to achieve, Smith (1994) proposed that, instead of a single basinwide strategy, the Columbia River Basin should be divided into 11 subbasins, each of which could develop its own solutions to the mix of social and ecological influences on salmon populations. Smith was proposing this division as a means of encouraging adaptive management, but it could also contribute to evolutionary problem solving. Smaller units, in addition to being amenable to cooperative management, might support various practices that enable evolutionary problem solving via innovation, diffusion, and adaptation of promising solutions to new situations. Unlike active adaptive management, evolutionary problem solving does not require imposition of an overall experimental design or agreement on a single metric of "success." However, it shares with active adaptive management the requirement for explicit and careful planning of the internal social context to facilitate its component processes. Wise choice of subbasin units, standardized and easily measured indicators, and structures promoting effective communication among the people involved are all essential for efficient evolutionary problem solving.

Conclusions

The challenges posed by information gaps in complex, socially embedded systems are not unique to resource management. Smithson (1988) identifies several well-known barriers to reducing uncertainty in such situations. The barriers tend to stem from multiple goals or values that cannot be maximized simultaneously. For example, "Collingridge's Dilemma" states that relatively new systems are usually easy and cheap to change, but people do not have enough experience with them to predict the effects of changes. By the time a system has been operating long enough for people to understand it, the well-entrenched status quo makes it expensive and difficult to implement changes. "Ravetz' Law" states that socially or politically important questions rarely are amenable to unique answers or normative consensus. Finally, the "Rationalist Quandary" notes that, as the language for representing uncertainty becomes more precise, specialized, and technically demanding, it becomes less useful for communicating with non-specialists, who thus may be excluded from discussion and debate. The expression and analysis of uncertainty as decimal probabilities, for example, tends to require a high level of mathematical sophistication, and it is frequently associated with errors in reasoning and interpretation (Anderson 1998; Gigerenzer 2000).

As in other areas of human endeavor, adaptive decisions can be made about ecological restoration, but the most useful approach will vary among situations according to the external social context, the problem itself, and the analytical resources, relationships, and abilities of people responsible for the decision. If the external social context presents the decision maker with uncertain goals, it is often helpful to understand conflicting social forces and try to articulate a coherent set of goals so that a wider array of decision processes can be used. For problems where the potential costs of technical uncertainty are relatively small, a static decision process such as a simple decision analysis can work well, as it clarifies the structure of the decision efficiently. Large and complex problems may call for more sophisticated decision processes from the "decision toolbox," such as passive or active adaptive management. Finally, where goals cannot be reconciled or clarified, a well-designed evolutionary process may result in improved practice over time.

A watershed restoration project is as much a social undertaking as an ecological one. Acceptance and understanding of the project will be enhanced if members of the public, in light of their own experience as adaptive decision makers, perceive the decision processes involved as clear, consistent, and adaptive.

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